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Climate change impacts on irrigation water requirement, crop water productivity and rice yield in the Songkhram River Basin, Thailand

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ABSTRACT

This study assesses the impacts of climate change on irrigation water requirement (IWR), rice yield, and crop water productivity (CWP) of the Thai Jasmine rice in the Songkhram River Basin of Thailand. The analysis was conducted using DSSAT crop simulation model with an ensemble of five Regional Circulation Models (RCMs) under RCP4.5 and RCP8.5 scenarios. The projection of future climatic conditions shows an increasing trend in both maximum and minimum temperatures which are expected to rise by 1.9 °C under RCP8.5 scenario by 2080s (2070–2094). Rainfall during the rainfed rice growing season may decrease in the 2030s (2020–2044), and increase in the 2055s (2045–2069) and 2080s for both scenarios. Although the total rainfall is expected to increase, rainfall during the rice reproductive phase (September to October) may decrease. The study also found that changes in rainfall have more significant influence on rice yield than temperature, possibly increasing water stress in the future. Temperature rises could increase crop water usage and higher rainfall alone may not be sufficient. IWR is expected to increase in the future. Rainfed rice yield may reduce by 14% under RCP4.5 scenario, and 10% under RCP8.5 scenario by 2080s. Due to the increment of crop water use and decrease in rice yield, CWP could reduce by 32% under RCP4.5 scenario, and 29% under RCP8.5 scenario by 2080s. The results of this study are helpful in formulating adaptation measures to address water stress and increase rice yield and CWP under climate change scenarios in the basin.

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1. Introduction

The agricultural sector in Thailand is large, covering 46.5% of the country's total land area in 2015 (Office of Agricultural Economics, 2017), and contributing to 8.3% of its Gross Domestic Product (GDP) in 2016 (Office of The National Economic and Social Development Board, 2017). Although GDP of agricultural contribution is small compared with other sectors, more than 34% of the Thai population depend on the agricultural sector for their living (Office of Agricultural Economics, 2015). Agricultural production is responsible for 16% of Thailand's exports, with the Northeast region being the largest producer, occupying 60% of the agricultural area. Rice production had the highest export value (172,241 million Thai Baht or 5519 million US Dollar) in 2016, with Thailand being the world's largest rice producer and exporter. Thai rice production accounted for 31.9 million tons under a paddy area of approximately 108,960 km^2 (approximately 21.3% of Thailand's total land area) in 2016 (Office of Agricultural Economics, 2017).

Thai Jasmine rice (also known as "Thai Hom Mali rice" or "KDML105"), a high-quality product, is grown mainly in the Northeastern part of Thailand. KDML 105 rice is a photoperiod sensitive variety, suitable for growing in the wet season (June to November), with planting taking place around June and July, flowering around October and harvesting by November (Office of Agricultural Economics, 2015).

The future climate is projected to change gradually. Global mean surface temperature could rise by up to 4.8 °C by the end of the 21st century and precipitation is likely to change depending on latitude (IPCC, 2014). Recent studies on future climate projections in Thailand have shown significant changes in temperature and rainfall. Thailand's temperature is expected to rise and precipitation may be higher with changing patterns in the future (Chinvanno and Southeast Asia START Regional Center, 2009).

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Climate change is likely to increase the water scarcity. Rising temperatures, a probable increase in the amount of evaporation, combined with more rainfall uncertainty have a significant influence on the irrigation water requirement, and climate change could affect future water availability worldwide. Ding et al. (2017) investigated the spatial and temporal responses of rice irrigation water requirements to climate change in the middle and lower reaches of the Yangtze River (MLRYR) in China and found that future climate change would increase irrigation requirement in most regions of the MLRYR whereas decreased irrigation requirement of single and late rice were found in the southern region of the MLRYR. Silva et al. (2007) also found that climate change would increase the average paddy irrigation water requirement by 23% (A2) and 13% (B2) in Sri Lanka.

Climate is one of the most important factors in agricultural productivity, and could directly influence it since it is linked to physiological processes. This issue could affect global food security, especially in developing countries. Climate change may have both positive and negative impacts on the quantity and quality of agricultural productions, depending on location, climate zone, and crops. Rice is one of the most important agricultural products in the world. A study conducted by Babel et al. (2011) projected a decline in the rice yield in the Northeast Thailand by 17.81, 27.59 and 24.34% for the 2020s, 2050s and 2080s, respectively, compared to the average yield during 1997–2006 under the ECHAM4 A2 climate change scenario. Similarly, Shrestha et al. (2017) studied the potential impact of climate change on rice yield in Northeast Thailand and found the decrease in yield for rice cultivars KDML105, and RD6. A decrease of yield by 37% and 38% is projected for KDML105 under RCP 4.5 and 8.5 respectively by 2080s. A decrease of yield by 13% and 18% is projected for RD6 under RCP 4.5 and 8.5 respectively by 2080s.Temperatures above 35 °C create high vulnerability of crops and could affect the ripening stage, significantly reducing rice production (Tipparak and Aroonrungsikul, 2011).

Future climate models or Regional Circulation Models (RCMs) are powerful tools for providing future regional climate information. However, individual climate models have different structures or parameter sets and may contain errors from various sources. Many studies on climate change impact assessment used single climate models. Studies suggested several techniques to reduce the uncertainty of future climate projections. Although RCMs may be downscaled for specific areas, they can still feature system errors. Therefore, more RCMs are necessary to address the uncertainties of climate models (Mishra et al., 2013). Wang et al. (2017) employed the Bayesian Model Averaging (BMA) method for future climate projection.

Climate is expected to change in the future, varying according to temperature and rainfall, leading to greater fluctuations in future water availability and IWR. This could significantly influence the quantity of available crops, with greater effects expected for rainfed agriculture. Crop simulation models are used to simulate the potential effects of future climate conditions on crop production. The use of future climate data and other datasets for crop simulation models with high resolution could help policymakers and managers better understand the impacts of climate change on crop yield.

Agriculture production in the Songkhram River Basin is sensitive to the changing climate. Most crops are grown during the rainy season as the basin has no dam along the river to store water for agricultural purposes during other seasons. Changing temperature and rainfall patterns in the basin directly impacts the agricultural sector. Since water in the Songkram River flows through the Mekong River, water availability is also dependent on the management of Mekong in the upstream.

In this study, the influence of climate change on rainfed rice season ("Thai Jasmine" or "KDML105" rice variety) in the Songkhram river basin, Thailand is considered. The potential impact of climate change on IWR, rice yield, and CWP are also evaluated. Future climate was projected based on multiple RCMs using Quantile mapping technique under two climate change scenarios (RCP4.5 and RCP8.5 scenarios). The RCP4.5 pathway is the intermediate stabilisation scenario, and RCP8.5 pathway is the highest greenhouse gas emission scenario. Hence, the study reduced the uncertainty of future climate models while considering possible future climate scenarios. DSSAT model was used to simulate crop growth, water requirement, and production using an ensemble of future climate. The outcomes of the study are useful for understanding the future climate, IWR, rice yield, and CWP under future climate change scenarios, which will serve as a reference for policymakers and stakeholders to provide strategies on paddy field management under future climate conditions.

2. Materials and methods

2.1. Study area

The Songkhram River Basin is the second largest catchment in Northeast Thailand with an area of approximately 12,700 km^2 (Fig. 1). The Songkhram River which drains the basin is approximately 420 km long and originates at the Phu Phan mountains in the Song Dao District of Sakon Nakhon Province and the Nong Han District in Udon Thani Province. It flows through the Mekong River at Chai Buri Sub-district and Tha Uthen District in Nakhon Phanom.

The basin has a tropical, semi-arid climate with three seasons: summer (March to May), rainy (June to October), and winter (November to February), and receives more annual rainfall than other parts of Thailand (Satrawaha and Wongpakam, 2012). The Thai Meteorological Department (TMD) reported variations in annual rainfall of between 1200 mm and 2000 mm, peaking during the months of July and August. The average mean temperature varies from 21 to 34 °C. The minimum temperature falls below 10 °C in the winter season during the months of December and January, and rises to over 40 °C during April in the summer season.

The basin is a floodplain, making it suitable for paddy fields. The Land Development Department (LDD) reported that majority of the land use in the basin is agriculture, covering approximately 68% of the land area. Most of the area consists of paddy fields, Pará rubber, and eucalyptus trees, taking up more than 90% of the agricultural land area in 2010. Household income is mainly reliant on agriculture (Satrawaha and Wongpakam, 2012).

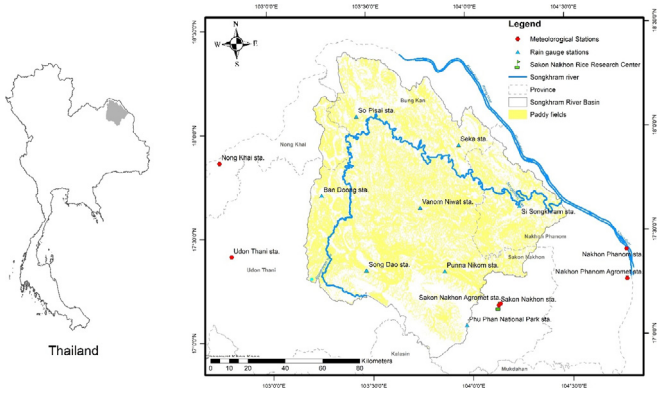

Fig. 1. Location of the meteorological stations, Sakon Nakhon Rice Research Center, and paddy fields in the Songkhram River Basin, Northeast Thailand.

2.2. Data inputs

The study uses data from eight rainfall stations operated by the Thai Meteorological Department (TMD), namely Ban Doong, Phu Phan National Park, Punna Nikom, Seka, Si Songkhram, So Phisai, Song Dao, and Wanon Niwat, distributed into the Songkhram River Basin. Since there is no temperature station in the basin, the six meteorological stations surrounding it, namely Nakhon Phanom, Nakhon Phanom Agromet, Nong Khai, Sakon Nakhon, Sakon Nakhon Agromet, and Udon Thani, represent its temperature (Fig. 1). The daily weather data, consisting of rainfall and maximum and minimum temperatures for the baseline period (1980–2004) are used to correct the RCMs climate data in the climate projection for future time periods from 2020 to 2094. The duration of study is divided into three time periods: the 2030s, 2055s, and 2080s. The years 2020–2044 are labelled as the 2030s, 2045–2069 as the 2055s, and 2070–2094 as the 2080s. The baseline period is applied to develop the DSSAT crop simulation model and as a base for evaluating the future climate.

Five RCMs are used in this study to project future climate: ACCESS1-CSIRO-CCAM, CNRM-CM5-CSIRO-CCAM, HadGEM2-AO-MOHC-HadGEM3-RA, ICHEC-EC-EARTH-SMHI-RCA4, and MPI-ESM-LR-CSIRO-CCAM with spatial resolutions of 0.5° latitude x 0.5° longitude. The three future periods under study are the 2030s, 2055s, and 2080s under two Representative Concentration Pathways (RCPs) namely RCP4.5 and RCP8.5 scenarios in the IPCC Fifth Assessment Report (AR5). RCPs are twenty-first-century pathways for greenhouse gas (GHG) emissions and atmospheric concentrations, air pollution, and land use (IPCC, 2014). The RCP4.5 scenario represents an intermediate stabilisation pathway where radiative forcing is approximately 4.5 W m^{-2} after 2100 (CO_2 concentrations between 580 and 720 ppm.). The RCP8.5 scenario assumes that radiative forcing reaches more than 8.5 W m^{-2} after 2100 (CO_2 concentrations higher than 1000 ppm).

The study analyses the rainfed KDML 105 rice variety. Its growing period is from June to August with harvesting taking place in November. The paddy field experiment and management practices have been conducted by Sakon Nakhon Rice Research Center in Sakon Nakhon Province, Northeast Thailand and are representative of those in the Songkhram River Basin. The relevant management practices are recorded such as sowing date, transplanting date, maturity date, harvest date, fertiliser application, and yield. The Land Development Department (LDD) records information on soil series and physical and chemical soil properties.

The methodology of the study is illustrated in Fig. 2. The Quantile Mapping (QM) method was adopted to correct the biasness of the five RCMs for the baseline period in order to project the future climate in the Songkhram River Basin for three future periods: the 2030s, 2055s, and 2080s under RCP4.5 and RCP8.5 climate scenarios.

The DSSAT crop simulation model version 4.6 was used to simulate the future IWR and rice yield. Rice experimental data from Sakon Nakhon Rice Research Center for 2009–2012 was used for calibration, and 2013–2014 for validating the model. The future IWR and rice yield were simulated using future climate to analyse the impact of climate change.

2.3. Climate change scenarios

Five RCMs were used to represent the future climate and evaluate the impact on future rice yield under RCP4.5 and RCP8.5 scenarios, according to the IPCC's Fifth Assessment Report (AR5). The selected RCMs (Table 1) are available at Coordinated Regional Climate Downscaling Experiment (CORDEX) (http://cordex.org/). CCAM models were developed by the Commonwealth Scientific and Industrial Research Organization (CSIRO), HadGEM3-RA model was developed by the Met Office Hadley Center (MOHC), and RCA4 was developed by the Swedish Meteorological and Hydrological Institute (SMHI).

Missing data can have significant effects on the results, hence the best option is to fill the missing values. In this study, the missing temperature data was estimated using the linear interpolation method and rainfall estimated using APHRODITE's gridded dataset (http://www.chikyu.ac.jp/precip/).

To reduce the error characteristics of the RCMs, the Quantile Mapping (QM) technique was applied for bias correction. The QM technique is based on daily constructed empirical cumulative distribution functions (ECDFs) and could improve the median, variance, frequency, intensity, and extremes (Themeßl et al., 2011). In addition, the technique improves the shape of the frequency distributions and quality of the original RCM (Themeßl et al., 2012). Five RCMs were corrected based on observed climate data obtained from TMD. Data from six temperature stations were used for correcting the maximum and minimum temperatures, and eight rain gauge stations were used for correcting the rainfall. The bias correction performance was evaluated using mean, standard deviation (SD), root mean square error (RMSE), and coefficient of determination (R^2). The ensemble of five RCMs was used to represent the future climate in the basin.

2.4. Crop simulation model

The DSSAT crop simulation model was used to simulate rainfed paddy growth and yield in the Songkhram River Basin under climate change conditions. Developed by a consortium of US universities, the DSSAT v.4.6 can simulate more than 42 crops, supported by database management programs for soil, weather, crop management, and experimental data (Hoogenboom et al., 2015). The model has been used for more than 20 years in over 100 countries worldwide with several studies adopting it to simulate rice yield at different locations in Thailand (Shrestha et al., 2017).

The model simulates crop growth and yield based on morphological and physiological characteristics. Genetic crop information and carbon balance are mainly used for simulation (Mishra et al., 2013). At least three sets of data are required to run the model: weather, soil, rice management practices. First, weather data includes the location of the weather station, daily rainfall, and the daily maximum and minimum temperatures gathered by the TMD. Daily solar radiation is calculated based on maximum and minimum temperatures (Hargreaves and Samani, 1985). Second, information on soil properties is gathered by the LDD and the rice experimental field located in the Roi Et soil series. Third, rice management practices are based on field experimental data from the Sakon Nakhon Rice Research Center. This study simulates crop growth and yield (KDML 105 rice variety) during the wet season. The model was calibrated and validated based on paddy field experiment data obtained from Sakon Nakhon rice research center in Thailand. Four years of experimental data (2009–2012) was used to set up and calibrate the model, and two years (2013–2014) for validation. The ensemble of future climate model was applied to project the future rice production. The crop model performance was evaluated using mean, root mean square error (RMSE), and coefficient of determination (R^2).

2.5. Irrigation water requirement (IWR), and crop water productivity (CWP)

This study assumed land use, soil characteristics, and crop management practices will remain the same in the future. Brouwer and Heibloem (2010) explained that IWR can be calculated from the

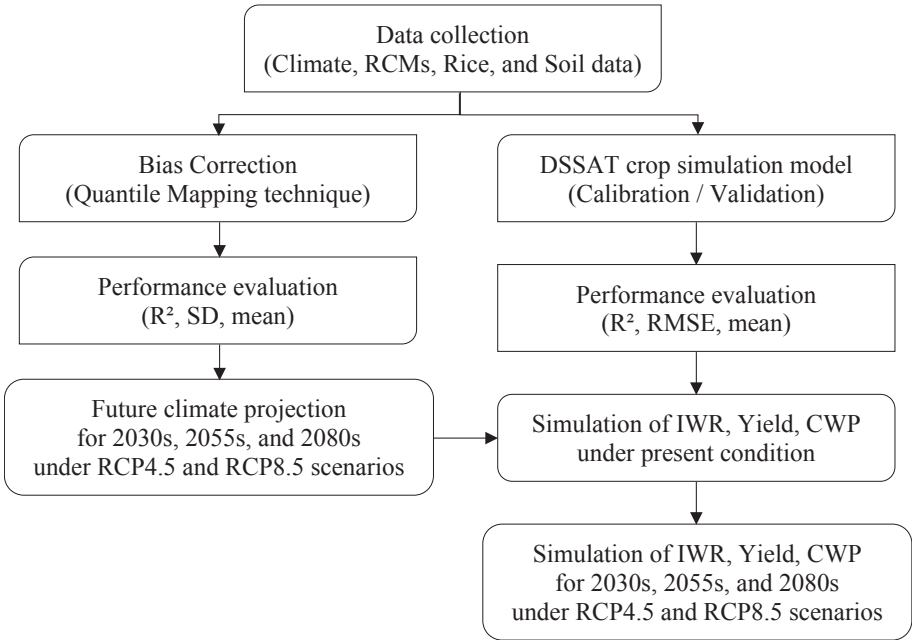

Fig. 2. Methodological framework for assessing the climate change impact on the irrigation water requirement (IWR), rice yield, and crop water productivity (CWP) for KDML105 rice variety during the wet season under RCP4.5 and RCP8.5 scenarios for future periods: 2030s, 2055s, and 2080s.

Table 1
Selected RCMs for projecting the future climate in the Songkhram River Basin under climate change scenarios.

RCM	Institute	Driving GCM	Resolution (latitude x longitude)
CCAM	Commonwealth Scientific and Industrial Research Organization (*CSIRO*)	ACCESS1.0	0.5° × 0.5°
CCAM	Commonwealth Scientific and Industrial Research Organization (*CSIRO*)	CNRM-CM5	0.5° × 0.5°
HadGEM3-RA	Met Office Hadley Center (MOHC)	HadGEM2-AO	0.5° × 0.5°
RCA4	The Swedish Meteorological and Hydrological Institute (SMHI)	ICHEC-EC-EARTH	0.5° × 0.5°
CCAM	Commonwealth Scientific and Industrial Research Organization (*CSIRO*)	MPI-ESM-LR	0.5° × 0.5°

difference between the crop water requirement (ETc, mm) and the effective rainfall (Pe, mm). The IWR is calculated by:

$$\mathbf{IWR} = \mathbf{ETc} - \mathbf{Pe} \quad (1)$$

where Pe is rainfall; effectively used by the plants and calculated by:

$$\mathbf{Pe} = \mathbf{R} - \mathbf{O} - \mathbf{E} - \mathbf{P} \quad (2)$$

where R is the total amount of rainfall (mm), O is runoff (mm), E is the amount of evaporation to the atmosphere (mm), and P is percolation (mm) during the growing period.

Rice yield and evapotranspiration values from the DSSAT model were used to estimate CWP, correlated with crop production and water use. CWP is calculated by:

$$\mathbf{CWP} = \mathbf{Y}/\mathbf{ETc} \quad (3)$$

where Y is the rice yield (kg ha^{-1}) and ETc is the total amount of season evapotranspiration (m^3 ha^{-1}) (Lou et al., 2015).

3. Results and discussion

3.1. Future climate scenarios

Projection of future temperatures suggest that both maximum and minimum temperatures are expected to increase. The maximum temperature could rise with variations between 0.7 and 1.1 °C for RCP4.5 scenario, and between 0.7 and 1.9 °C for RCP8.5 scenario. The magnitude of increment under RCP8.5 scenario is higher than that of RCP 4.5 scenario. The maximum temperature under RCP4.5 scenario may peak during the middle period (2055s), in contrast with that under the RCP8.5 scenario, which continually increases and could rise by up to 1.9 °C by the end of the period (2080s).

The minimum temperature could vary by between 0.4 and 1.3 °C for RCP4.5 scenario, and between 0.6 and 1.9 °C for RCP8.5 scenario. The temperature could peak under RCP4.5 scenario during the middle period (2055s), rising by up to 1.3 and 1.9 °C under RCP8.5 scenario for the middle and last periods (2055s and 2080s). The projected change in maximum and minimum temperatures during the rainfed rice period for three future periods (2030s, 2055s, and 2080s) under climate change scenarios is shown in Table 2, and the trends of maximum and minimum temperature are shown in Fig. 3, and Fig. 4.

The results suggest that the amount of rainfall during the rainfed growing period may reduce in the near future (2030s) by 17% from the baseline for both scenarios, but increase in the middle and last periods (2055s and 2080s). Under RCP4.5 and RCP8.5 scenarios respectively, rainfall could be higher by 15% and 12% during the middle period (2055s), and 11% and 9% during the last period (2080s). The projected percentage change in rainfall during the rainfed rice period for the 2030s, 2055s, and 2080s under climate change scenarios is shown in Table 2, and the monthly rainfall in Fig. 5.

Table 2
Changes in maximum and minimum temperature, and rainfall during the rainfed rice growing season (July to November) for three future periods (2030s, 2055s, and 2080s) under RCP4.5 and RCP8.5 scenarios.

Climatic parameters	Baseline (1980–2004)	Changes					
		RCP4.5			RCP8.5		
		2030s (2020–2044)	2055s (2045–2069)	2080s (2070–2094)	2030s (2020–2044)	2055s (2045–2069)	2080s (2070–2094)
Maximum temperature	31.2 °C	0.7 °C	1.1 °C	0.8 °C	0.7 °C	1.6 °C	1.9 °C
Minimum temperature	22.7 °C	0.4 °C	1.3 °C	0.5 °C	0.6 °C	1.9 °C	1.9 °C
Rainfall	827 mm	−17%	15%	11%	−13%	12%	9%

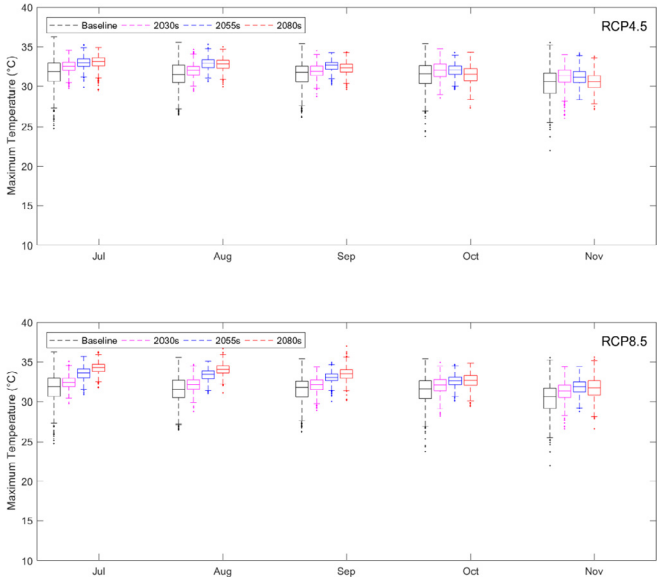

Fig. 3. Projected average maximum temperature during the rainfed rice growing period under RCP4.5 and RCP8.5 scenarios.

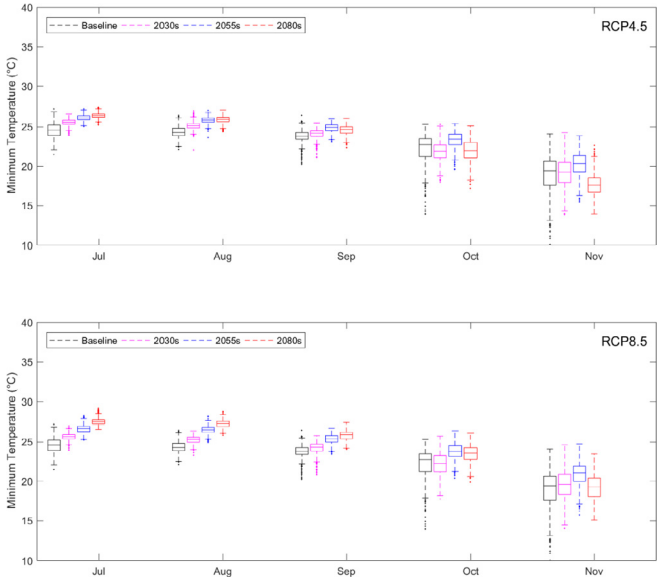

Fig. 4. Projected average minimum temperature during the rainfed rice growing period under RCP4.5 and RCP8.5 scenarios.

Thailand's climate is gradually changing. TMD reported that the historical average temperature is continuously rising, with rainfall

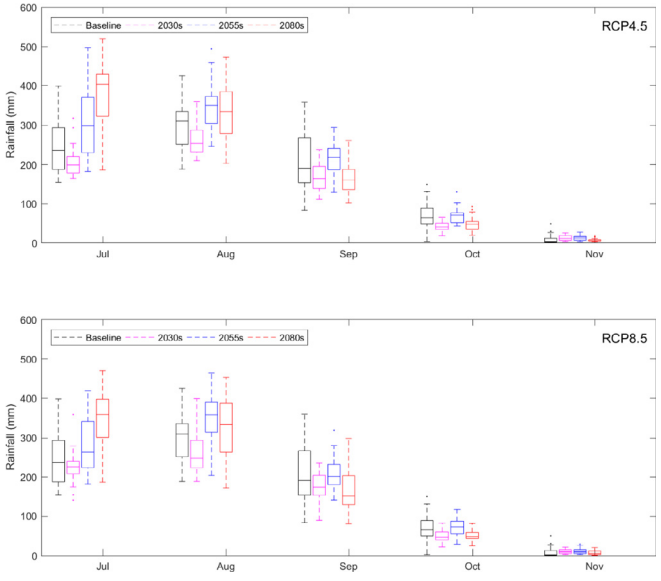

Fig. 5. Projected monthly rainfall during the rainfed rice growing period under RCP4.5 and RCP8.5 scenarios.

becoming more variable, showing an increasing trend. Chinvanno and Southeast Asia START Regional Center (2009) projected the future climate for Thailand and surrounding countries based on an ECHAM4 A2 scenario using the PRECIS regional climate model. The change in average temperature is projected to increase by approximately 2–3 °C and the future rainfall may be higher by 25–50%. Chinvanno and Choengbunluesak (2006) studied the future climate in the Songkhram River Basin using CO_2 concentrations and found that the basin can be approximately 1–2 °C warmer, with an increasing annual rainfall of over 8% when CO_2 is 720 ppm. Similar studies in Thailand (Shrestha et al., 2017) also found that the future maximum and minimum temperatures may rise in the future along with rainfall. This recent research supports the results of this study.

3.2. Calibration and validation crop simulation model

DSSAT crop simulation model simulates crop growth and yield based on genetic coefficient information. Buddhaboon et al. (2004) reported the genetic coefficient for KDML 105 in the study area and hence used in the crop simulation model (Table 3).

Four years of experimental data (2009–2012) was used to set up and calibrate and validate the model, and results show that the observed and simulated rice yield matched well (Table 4). The DSSAT model simulated the rice yield with a coefficient of determination (R^2) value of 0.84. The average observed yield was 1.96 ton ha^{-1}, and the average simulated yield was 1.92 ton ha^{-1}, with

Table 3
Genetic coefficient for KDML105 rice variety.

Genetic coefficient	Value	Description
P1	502.3	Basic vegetative phase of the plant
P2R	1233.0	Photoperiod sensitivity in panicle initiation
P5	386.5	Grain filling duration
P2O	12.7	Critical photoperiod of development occurring at a maximum rate
G1	45.7	Potential spikelet number coefficient
G2	0.0270	Single grain weight
G3	1.00	Tillering coefficient
G4	0.95	Temperature tolerant coefficient

Table 4
DSSAT simulation model performance evaluation for the KDML 105 rice variety during the wet season.

Year	Mean rice yield (ton ha^{-1})		RMSE (ton ha^{-1})	R^2
	Observation	Simulation		
2009–2012	1.96	1.92	0.009	0.84

the RMSE estimated as 0.009 ton ha^{-1}. In addition, the simulated model validation for two years (2013–2014) showed an average observed yield of 2.08 ton ha^{-1}, and an average simulated yield of 2.07 ton ha^{-1}.

Many factors affect rice yield. This study considers only changes in weather under climate change scenarios and assumes that crop management practices such as fertiliser application remained unchanged. The calibration and validation results indicate a better performance for the crop simulation model, therefore it is suitable for simulating rice yield under future climate conditions for the Songkhram River Basin.

3.3. Impact of rainfall change and temperature change on rice yield

The DSSAT crop simulation model was developed on the basis of four years' data (2009–2012). The weather in 2009 was normal with no extreme events, similar to the mean of 30 years' weather in the Sakon Nakhon Province recorded by the TMD. Therefore, the rainfall and temperature in 2009 were used to represent the future climate for simulating the impact of rainfall and temperature changes on rice production.

Fig. 6 illustrates the impact of rainfall change and temperature change on rainfed rice yield. The results suggest that the changing rainfall has a significant impact on rice yield. Although changing temperatures do not show significant influences, temperature rise could increase evaporation and evapotranspiration, and in turn, crop water requirement.

3.4. Climate change impact on the irrigation water requirement (IWR)

The results suggest that the average IWR will increase in the future. Temperatures rise could increase the evaporation and transpiration rate which would also influence the IWR. Fig. 7 shows the trend of future IWR under both RCP4.5 and RCP8.5 scenarios. The crop water requirement is expected to increase in the future, and although more rainfall is expected, it may not be sufficient to address the issue. The results from the model in Table 5 indicate that the IWR may increase under both scenarios.

Brouwer and Heibloem (2010) reported that paddy needs between 450 and 700 mm of water during the growing period and is highly sensitive to drought conditions. This study supports these results, with a simulated rice water requirement varying between

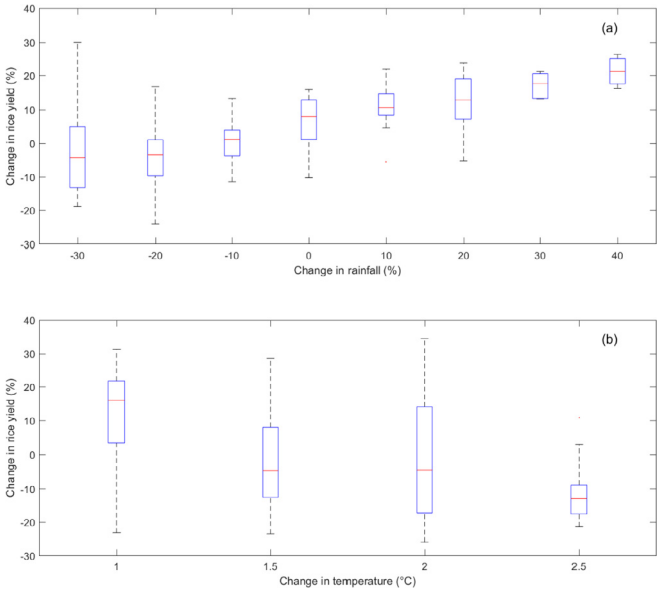

Fig. 6. Simulated impact of (a) rainfall change and (b) temperature change on rice yield.

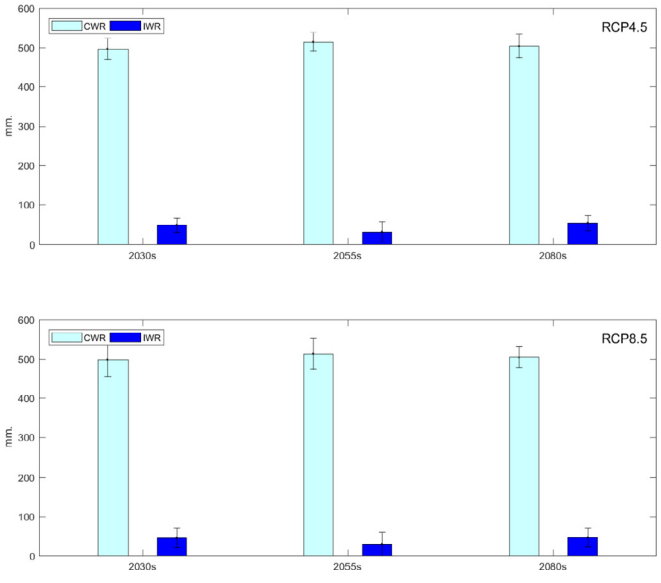

Fig. 7. Projected crop water requirement (CWR), and irrigation water requirement (IWR) under RCP4.5 and RCP8.5 scenarios for three future periods (2030s, 2055s, and 2080s).

427 and 514 mm. Recent studies also suggest that increased temperatures and changes in rainfall patterns can significantly increase

Table 5
Projected crop water requirement (CWR), effective rainfall, irrigation water requirement (IWR), and rice yield during the rainfed rice growing season (July to November) for three future periods (2030s, 2055s, and 2080s) under RCP4.5 and RCP8.5 scenarios.

Variable	Baseline (2009–2012)	RCP4.5			RCP8.5		
		2030s (2020–2044)	2055s (2045–2069)	2080s (2070–2094)	2030s (2020–2044)	2055s (2045–2069)	2080s (2070–2094)
CWR (mm)	427	496	514	503	498	513	504
Effective rainfall (mm)	410	448	483	450	452	485	457
IWR (mm)	17	48	31	53	46	28	47
Rice yield (t ha^{-1})	1.93	2.06	1.73	1.65	1.90	1.78	1.73
Change in rice yield (%)		−6.59	−10.20	−14.36	−1.69	−7.81	−10.36

the IWR. Rising temperatures may be the main reason for the increase in CWR. The IWR is expected to increase in many countries due to climate change. Silva et al. (2007) reported that the paddy IWR could increase by 23%. However, its impact could be mitigated (Shrestha et al., 2016).

3.5. Future rice yield projection

Climate change can significantly influence agricultural production. Moreover, increasing temperature and rainfall uncertainty can reduce crop. Fig. 8 shows that the trend of rainfed rice yield is continually decreasing. In addition, the rice yield will increase by 6.59% in the 2030s and reduce by 10.20 and 14.36% for the 2055s and 2080s, respectively under the RCP4.5 scenario. In contrast, the rice yield can decrease by 1.69, 7.81, and 10.36% for the 2030s, 2055s, and 2080s, respectively under the RCP8.5 scenario. The RCP 4.5 scenario has a greater magnitude of impact for reducing rice production than the RCP 8.5 scenario in the last periods (2055s and 2080s), and rice yield may vary more in the 2080s. The impact of climate change on rice yield depends on the varieties or cultivars used since some may receive a positive impact (increased yield) from climate change.

The impact of climate change on the IWR and rice yield for the KDML 105 rice variety during the wet season suggests that climate change (change in temperature and rainfall), could affect rice yield. The results show that temperature rises significantly influence the quantity of rice yield, both directly and indirectly. Although water stress does not occur in the second period (2055s), rice yield could decrease as a result of temperature rise. Results for the 2080s show that higher water deficit could reduce rice yield.

Future KDML 105 (photoperiod sensitive rice variety) rice growth and yield could reduce as a result of many factors, including temperature rise, reduction in sunshine hours, higher IWR, and changes in rainfall pattern. Temperature rises could affect many stages of rice growth such as a decline in the grain filling period, spikelet sterility, and losses during respiration which could reduce the quantity and quality of rice production. This study considers only daily maximum and minimum temperatures and does not take into account variations throughout the day, which may also affect rice yield. In addition, since KDML 105 growth is based on sunlight (photoperiod sensitive), lights on roads at night may affect rice growth and production.

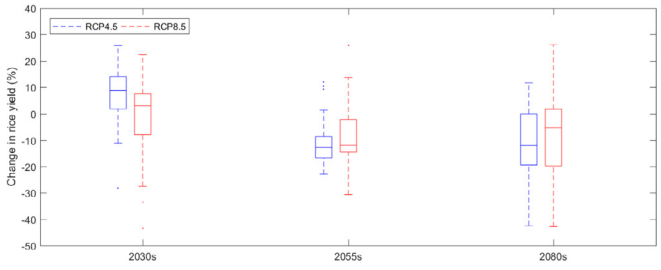

Fig. 8. Projected change in rice yield under RCP4.5 and RCP8.5 scenarios.

3.6. Climate change impact on crop water productivity (CWP)

Water productivity for the KDML 105 variety during the baseline period (2009–2012) was 0.42 kg rice m^{-3} water, ranging from 0.34 to 0.50 kg rice m^{-3} water. Tsubo et al. (2007) reported that water productivity for the KDML 105 variety in Northeast Thailand varies from 0.3 to 0.9 kg rice m^{-3} water. Doorenbos and Kassam (1979) reported that water productivity varies from 0.7 to 1.1 kg rice m^{-3} water, depending on many factors such as the paddy field location, rice variety, and management practices.

In this study future CWP is expected to decrease due to increases in temperature and crop water use. Table 6 indicates that future water productivity may decrease by 9.52–32.14% and 10.71–28.57% under RCP4.5 and RCP8.5 scenarios, respectively. Temperature rises cause the crop water requirement to increase, creating a significant decrease in rice yield (Wang et al., 2012).

4. Conclusions

The future irrigation water requirement (IWR), yield, and crop water productivity (CWP) of Thai Jasmine rice were investigated under climate change scenarios for the Songkhram River Basin in Thailand. Future climate projections during rainfed rice season (July to November) indicate that maximum and minimum temperatures are expected to rise in the future for all periods, increasing up to 1.9 °C by the 2080s under RCP8.5 scenario. Although the amount of rainfall during rainfed rice season is expected to be higher under both scenarios, the average future monthly rainfall is expected to increase in July and August, but decrease in September and October under both scenarios. Simulation of future rice growth and yield using DSSAT crop simulation model found that IWR is expected to increase due to higher crop water requirement (CWR) caused by temperature rise. Although the amount of rainfall is expected to increase in the future, temperature rise might be more severe, thereby increasing evaporation as well as the CWR. Decreasing future rainfall during the reproductive phase of rice growth (September to October) can have a significant influence on the rice yield. Furthermore, the rice yield is projected to continually decline in the future under both scenarios. Future rice yield may reduce by 14.36% and 10.36% under RCP4.5 and RCP8.5 scenarios respectively by 2080s. Decreasing rice yield combined with water deficit in the future would decrease the future crop water productivity (CWP). CWP can decrease by 32.14% and 28.57% under RCP4.5 and RCP8.5 scenarios respectively by 2080s. The study also found that changes in future rainfall has more significant influence on rainfed rice yield than future temperature changes. The results of this study provide useful information which could be used by policymakers and stakeholders to formulate suitable adaptation strategies to offset

Table 6
Projected crop water productivity (CWP) for three future periods under RCP4.5 and RCP8.5 scenarios.

Scenarios	Periods	Crop water productivity		
		Range (kg m^{-3})	Mean (kg m^{-3})	Change (%)
	Baseline (2009–2012)	0.34–0.50	0.42	
RCP4.5	2030s (2020–2044)	0.29–0.47	0.38	−9.52
	2055s (2045–2069)	0.30–0.42	0.36	−14.29
	2080s (2070–2094)	0.14–0.43	0.29	−32.14
RCP8.5	2030s (2020–2044)	0.28–0.47	0.38	−10.71
	2055s (2045–2069)	0.28–0.45	0.37	−13.10
	2080s (2070–2094)	0.14–0.46	0.30	−28.57

the negative impacts of climate change on rice production. Water management strategies such as construction of water storage structures, irrigation planning or soil moisture management will be helpful for reducing water deficit for rainfed rice, especially for KDML105 or Jasmine rice variety in the Songkhram River Basin, Thailand.

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